CHAPTER TWO

CEMENT INDUSTRY OVERVIEW

2.0 INTRODUCTION AND DESCRIPTION OF CKD

CKD is a fine-grained solid material generated as the primary by-product of the production of cement. Cement production occurs in very large rotary kilns at high temperatures; finely ground raw material enters and rolls downward from the "cool end" of the kiln, while fuels and combustion air are introduced and drawn upward from the "hot end." This air that is drawn into and through the kiln carries with it some of the finely ground solid raw materials, condensed fuel components, and partially reacted feed. As this air exits the cool end, the entrained solid matter is collected before the air is vented to the atmosphere, through the large gas emission "smokestacks" that are found at all cement production facilities. CKD generation results directly from this control of particulate matter that would otherwise be discharged. In contrast to many other residues of industrial production, CKD is essentially an "off-specification" product; it much more closely resembles the raw materials entering and product leaving the operation than many other industrial solid wastes. The effective control of stack emissions at cement plants has occurred only during the past 30 years or so. Therefore, the generation of CKD as a "solid waste" in significant quantities is a relatively recent phenomenon. Nonetheless, existing stockpiles of this material are quite large at some facilities, and substantial quantities of additional CKD are generated (though not necessarily accumulated) on a continuous basis at all cement plants.

All cement kilns generate CKD, and the quantities and characteristics of the CKD generated depend upon a number of operational factors and characteristics of the inputs to the manufacturing process. A critical examination of CKD management and its impacts cannot be conducted without an understanding of the industry and the basic process of manufacturing cement. Accordingly, this section presents an overview of the cement industry and describes cement types, the basic structure of the cement industry, manufacturing processes, and variations in kiln design. A section on process inputs provides discussion of the characteristics of the raw feed and the fuels used in the manufacturing process. This overview should assist the reader in understanding some of the issues surrounding the chemical characteristics of CKD that are discussed in considerable detail in subsequent chapters of this report. This chapter concludes with a brief summary and "road map" to the remainder of this document.

2.1 CEMENT INDUSTRY STRUCTURE AND CHARACTERISTICS

2.1.1 What Is Cement?

For purposes of this Report to Congress, cement refers to the commodities that are produced by burning mixtures of limestone and other minerals or additives at high temperature in a rotary kiln, followed by cooling, finish mixing, and grinding. This is the manner in which the vast majority of commercially-important cementitious materials are produced in the United States. Cements are used to chemically bind different materials together. The most commonly produced cement type is "Portland" cement, though other standard cement types are also produced on a limited basis. The major cement types and their applications are presented in Exhibit 2-1. Portland cement is a hydraulic cement, meaning that it sets and hardens by chemical interaction with water and is capable of doing so under

Exhibit 2-1

General Cement Types and Uses

Cement Name	Type	Characteristics	Uses
Normal Portland Cement	I	Non-specialty hydraulic cement	Most structures, pavements, and reservoirs.
Modified Portland Cement	II	Generates less heat from its hydration and is more resistant to sulfate attacks than type I.	Structures having large cross sections, such as large abutments and heavy retaining walls. Also in drainage where a moderate sulfate concentration exists.
High-Early-Strength Portland Cement	III	Allows earlier removal of forms and shorter periods of curing.	When high strengths are required within a few days.
Low-Heat Portland Cement	IV	Generates less heat during hydration than type II. Gains strength more slowly than type I. The tricalcium aluminum content is limited to seven percent.	Mass concrete constructions such as large dams where high temperature rises would create special problems.
Sulfate-Resisting Portland Cement	V	High sulfate resistance cement that gains strength more slowly than type I. The tricalcium aluminate content is limited to a maximum of five percent.	Special cement, not readily available, to be used when concrete is exposed to severe sulfate attack.
Air-Entraining Portland Cements	IA IIA IIIA	Air-entraining agents, interground with the cement clinker, purposely cause air, in minute, closely spaced bubbles, to occur in concrete.	Entrained air makes the concrete more resistant to the effects of repeated freezing and thawing and of the deicing agents used on pavements.
Portland-Blast Furnace Slag Cements	IS IS-A MH MS	Made by grinding granulated high-quality slag with Portland-cement clinker. Type IS cements gain strength more slowly in initial stages, but ultimately have about the same 28-day strength as type I cements.	Air entrainment type is IS-A; Moderate heat-of-hydration type is MH; Moderate sulfate resistance type is MS.
White Portland Cement	N/A	Desirable aesthetic qualities. High in alumina and contains less than 0.5 percent iron.	Architectural and ornamental work.
Portland-Pozzolan Cement	IP IP-A	A blended cement made by intergrinding Portland cement and pozzolanic materials (slaked lime and granulated blast-furnace slag or other material similar to natural lava), without burning.	Used under certain conditions for concrete not exposed to the air. Air entrainment type is IP-A. Covered in ASTM specification C3-40.
Masonry Cement	C91 (ASTM)	Hydraulic cement made by combining either natural or Portland cements with fattening materials such as hydrated lime and, less frequently, with air-entraining admixtures.	Used in place of job cement-lime mixtures to reduce the number of materials handled and to improve the uniformity of the mortar.

Exhibit 2-1 (continued)

General Cement Types and Uses

Cement Name	Type	Characteristics	Uses
Waterproofed Cements	N/A	Produced by grinding with certain soaps and oils.	Sometimes used where a waterproof or water-repellant concrete or mortar is desirable. The effectiveness is limited to three or four feet of water pressure.
Natural Cement	N/A	Manufactured from limestone containing clay, with chemical constituents similar to those of Portland cement.	Sometimes used as common mortar for brick or stonework.

Note: N/A = not applicable
Source: Adapted from Baumeister and Marks, 1968. *Standard Handbook for Mechanical Engineers*.

water.[1] When combined with sand, gravel, water, and other materials, Portland cement forms concrete, the most widely used building material in the world. Portland cement comprises about 90 percent of all hydraulic cement produced, with masonry, lime, and natural cements constituting the remainder. Cement produced and sold in the U.S. must meet specifications established by the American Society for Testing and Materials (ASTM). Five types of Portland cements are covered by ASTM specifications (number C150). Each type requires specific additives or changes in the proportions of the raw material mix to make products for specific applications.

Together, Portland and masonry cement consumption exceeded 69 million metric tons (76 million tons) in 1991,[2] far surpassing the use of all other cement types combined. Seventy-three percent of all U.S. cement is used by the ready mix concrete industry, while 12 percent is used by concrete product producers (pipe, pre-cast, and prestressed), and 5 percent is used by highway contractors. Other users include building materials dealers and other contractors. Most of the Portland cement sold in the U.S. is shipped in bulk form, with less than 5 percent of the total being shipped in bags.[3]

Portland cement concrete is utilized in a wide variety of construction applications, including houses, offices, roads, sidewalks, playgrounds, and water supply systems. Use in buildings accounts for approximately 60 percent of all cement consumption. Half of this is for residential buildings, approximately 20 percent for commercial buildings, and the remainder for public and farm buildings.[4] Public infrastructure development and maintenance accounts for the remaining 40 percent of cement demand.[5] The majority of public infrastructure applications are

[1] American Concrete Institute, 1990. *Cement and Concrete Terminology*, American Concrete Institute Committee 116, publication SP-19 (90), Detroit, Michigan.

[2] Portland Cement Association, 1992a. *U.S. Cement Industry Fact Sheet*, 10th Edition, Market and Economic Research, Skokie, Illinois. April 1992.

[3] U.S. Department of Commerce, 1991. *Cement Industry, U.S. Industrial Outlook 1991*, Washington, D.C.

[4] *Ibid*.

[5] Sanborn, S., 1992. *Cement & Aggregates*, Value Line Publishing. July 24, 1992.

for streets and highways, but other important applications include water and waste systems, burial vaults, and oil wells.[6] As discussed in more detail below, cement producing facilities in the United States generally serve local and regional markets.

Portland cement consists of a mixture of synthetic materials or compounds. The four principal compounds are:

- Tricalcium silicate - $(CaO)_3SiO_2$;
- Dicalcium silicate - $(CaO)_2SiO_2$;
- Tricalcium aluminate - $(CaO)_3Al_20_3$); and
- Tetracalcium-aluminoferrite - $(CaO)_4(Al_2O_3)(Fe_2O_3)$.

Portland cement can be defined as "the product obtained by finely grinding clinker produced by calcining to incipient fusion (i.e., sintering) an intimate and properly proportioned mixture of argillaceous and calcareous materials."[7] Roughly translated, cement is made by sintering a mixture of materials containing lime, silica, alumina, and iron oxide. Typically, these materials include limestone, sand, clay, iron ore, and/or other minerals and mineral processing residues.

Cement production involves heating these raw materials, usually limestone and clay, to approximately 1,482°C (2,700°F) to form a material called "clinker," which is granular and highly variable in size. Clinker is then cooled, and ground with a smaller amount (approximately five percent) of gypsum to make cement. The heating process is performed in a rotary cement kiln, which is a brick-lined cylinder, inclined slightly from the horizontal, that rotates on its longitudinal axis at a slow and constant speed (generally a couple of revolutions per minute). Raw materials are introduced at the higher end, while a fixed combustion source is operated at the lower end. Thus, the raw materials and the heated air (which induces the chemical reactions in the raw feed) travel countercurrent to one another. There are a number of different cement kiln configurations that employ different technologies and equipment, and thus, there is considerable variation in the size and operating characteristics of cement kilns. Nonetheless, cement kilns are all quite large in comparison with most other types of industrial equipment; typical cement kilns are approximately 152.4 meters (m) long (500 feet) and 3.7 m in diameter,[8] and some are considerably larger. There are two primary types of kiln design: wet process kilns that accept feed materials in slurry form, and dry process kilns that accept feeds in dry, ground form. A more detailed description of the cement production process and its variations is presented in Section 3.2, below.

2.1.2 The Cement Industry

Because cement is used in almost all construction activities, the cement industry is an important part of the nation's economic and industrial base. Figures characterizing the cement industry, such as production, capacity, and consumption statistics, change as a result of fluctuations in domestic construction activities, plant modernizations, economic conditions, and the level of cement imports. In 1991, reported consumption of Portland and masonry cement in the U.S. was 69.3 million metric tons (76.3 million tons), representing the lowest consumption

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[6] U.S. Department of Commerce, 1991, *op. cit.*

[7] "Portland Cement", Kackman, A.H. and Brown, R.W., Section Editors; *SME Mineral Processing Handbook*, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, NY, 1985, Vol. 2, Section 26, pp. 26-1 to 26-52.

[8] Environmental Toxicology International, 1992. *All Fired Up: Burning Hazardous Waste in Cement Kilns*, Seattle, Washington.

since the early 1980s.[9] The companies that comprise the U.S. cement industry, and the number and location of the plants that they operate are presented in Appendix B-1.

The most recent figures on clinker production are from 1990.[10] In 1990, the domestic cement industry consisted of 43 companies operating 115 clinker-producing plants, consisting of 218 kilns, in 37 states and Puerto Rico. Total domestic clinker production in 1990 was nearly 65.4 million metric tons, comprising an 85.7 percent utilization of the total available capacity of close to 76.2 million metric tons. Dry kilns accounted for approximately 45 million metric tons of this production, representing over 65 percent of the total. The slight dominance in terms of production by dry kilns reflects the recent trend toward greater reliance on this more energy-efficient process.

California was the largest clinker producing state in 1990, followed by Texas, Pennsylvania, Missouri, and Michigan. Exhibit 2-2 presents 1990 clinker production by state. This geographic distribution reflects the regional nature of the industry. Because of the low value-to-weight ratio of cement and the resulting high relative cost of transportation, most cement plants are located within 321.9 kilometers (200 miles) of their principal markets.[11] Therefore, the states with the largest populations and economies, which have enjoyed dynamic construction trends, tend to be the largest cement markets and also the largest cement producers. There has been little change over the past 30 years in terms of the largest cement-consuming states; California, Texas, and Florida have been the leaders throughout this period.

Exhibit 2-3 presents the geographic distribution of cement plants across the U.S. The location of plants also corresponds roughly to the location of the larger cement markets. California, Texas, and Pennsylvania each had 11 cement facilities in 1990. These larger states contain several distinct markets, each with multiple cement producers supporting the construction requirements of individual metropolitan areas. On the other hand, there are a number of one-plant companies that serve the needs of a particular regional market and a number of states that exist as individual cement markets. In addition, 13 states and the District of Columbia currently have no cement-producing plants and rely upon cement supplies from other (usually adjacent) states. The 13 states are:

[9] Portland Cement Association, 1992b. *U.S. and Canadian Portland Cement Industry: Plant Information Summary 1991*, Market and Economic Research, Skokie, Illinois. August, 1992.

[10] Production statistics for this report were derived from capacity information presented in the 1991 PCA facility survey and capacity utilization data reported by the U.S. Bureau of Mines. For more detailed information on the derivation of these data, refer to Appendix B-2.

[11] The exception to this distance limitation comprises those production facilities that have ready access to water transportation, enabling them to extend their marketing areas through the use of distribution terminals. Although ultimate delivery of cement to the consumer is almost always performed by truck, 90 percent of shipments from production plants to distribution terminals are done by rail and waterway (Environmental Toxicology International, 1992, *op. cit.*)

Exhibit 2-2

1990 Clinker Production by State

State	Number of Plants	Number of Kilns			Reported Capacity (tons per year)[a]	Reported Capacity Utilization	Calculated Production (tons clinker)
		Wet	Dry	Total			
CALIFORNIA	11	1	19	20	10,389,000	85.0%	8,830,650
TEXAS	11	9	11	20	7,853,940	89.0%	6,990,007
PENNSYLVANIA	11	8	15	23	5,226,000	81.8%	4,274,868
MISSOURI	5	2	5	7	4,158,000	99.8%	4,149,684
MICHIGAN	4	3	6	9	3,866,390	98.6%	3,812,261
ALABAMA	5	0	6	6	4,096,000	74.9%	3,067,904
INDIANA	5	3	6	9	2,794,900	97.4%	2,722,233
NEW YORK	4	4	1	5	2,941,630	86.1%	2,532,743
IOWA	4	2	4	6	2,498,000	99.8%	2,493,004
SOUTH CAROLINA	3	6	1	7	2,493,570	95.5%	2,381,359
ILLINOIS	4	0	8	8	2,265,000	98.4%	2,228,760
FLORIDA	4	5	3	8	2,816,700	71.4%	2,011,124
PUERTO RICO	2	4	2	6	2,188,007	78.8%	1,724,150
MARYLAND	3	2	5	7	1,750,000	93.7%	1,639,750
KANSAS	4	4	7	11	1,737,144	80.4%	1,396,664
OKLAHOMA	3	2	5	7	1,791,000	74.0%	1,325,340
ARIZONA	2	0	7	7	1,640,000	71.6%	1,174,240
OHIO	3	4	1	5	1,507,000	76.0%	1,145,320
VIRGINIA	1	0	5	5	1,100,000	87.9%	966,900
GEORGIA	2	0	3	3	1,082,730	87.6%	948,471
ARKANSAS	2	5	0	5	1,239,000	69.1%	856,149
UTAH	2	2	1	3	853,000	99.7%	850,441
COLORADO	3	1	2	3	1,250,000	66.8%	835,000
TENNESSEE	2	2	1	3	940,000	87.6%	823,440
14 OTHER STATES	15	12	13	25	7,506,400	80.3%	6,027,639
Totals	**115**	**81**	**137**	**218**	**75,983,411**	**85.7%**	**65,117,783**

[a] These numbers have been converted from short tons per year as reported in the source.

Source: Capacity data derived from facility responses to the 1991 PCA Survey, 1992 North American Cement Directory, and the Bureau of Mines 1990 Annual Report on Cement. Utilization data taken from the Bureau of Mines 1990 Annual Report on Cement.

Exhibit 2-3

Geographic Distribution of Active Portland Cement Production Facilities in 1991 in the U.S.

Source: Portland Cement Association, 1992b, *op*. *cit*.

Alaska	Minnesota	North Dakota
Connecticut	New Hampshire	Rhode Island
Delaware	New Jersey	Vermont
Louisiana	North Carolina	Wisconsin
Massachusetts		

In 1990 the five largest U.S. cement companies in terms of clinker production were as follows: Holnam, Incorporated; Lafarge Corporation; Lehigh Portland Cement Company; Lone Star Industries; and Southdown, Incorporated. These companies also ranked identically in terms of capacity, with the top five accounting for approximately 39 percent of industry clinker capacity. Clearly, the cement industry is not one with highly concentrated ownership; the five largest producers in many other types of manufacturing industries account for 80 percent or more of the total industry capacity.[12]

Nevertheless, the structure of the domestic cement industry has changed radically over the last 20 years. There are now fewer companies with one- and two-plant operations, and many established cement companies are out of business or have sold off their holdings. In general, the industry has been shrinking in terms of capacity over the last decade. Exhibit 2-4 presents U.S. clinker capacity for the period 1973-1991. Also, foreign ownership of U.S. clinker capacity has increased from 5 percent in the late 1970s to over 70 percent in 1992.[13] Both Holnam Inc. and Lafarge Corporation are foreign owned.[14]

Seasonal cycles are typical in the cement industry. Demand during peak summer months may be three times that of a winter month. Typically, a cement producer will build up inventories during the winter months in anticipation of peak demands during the summer construction period. Trade literature reports that about two thirds of U.S. cement consumption generally occurs during the six month period from May to October.

Historical data document the fact that trends in cement consumption generally follow trends in construction activity. In the past, the cement industry has experienced prolonged cycles in activity over 15 to 20 years, as well as the shorter traditional business cycles.

Imports of cement usually account for a small percentage of total U.S. cement consumption. Historically, cement and clinker importation has been highly cyclical, but still has only accounted for between three and 11 percent of consumption. The 11 percent figure occurred in 1979, and the lower figures generally appear during the later stages of recessionary periods. Higher rates of importation usually occur when plants are operating at full capacity and are still unable to meet consumer requirements. Imports of cement tend to affect domestic coastal markets, like Florida and California, to a greater degree, because in these markets, costly ground transportation of cement product to consumers is not required. Historically, it has been Canada, Japan, Spain, and Mexico that have been

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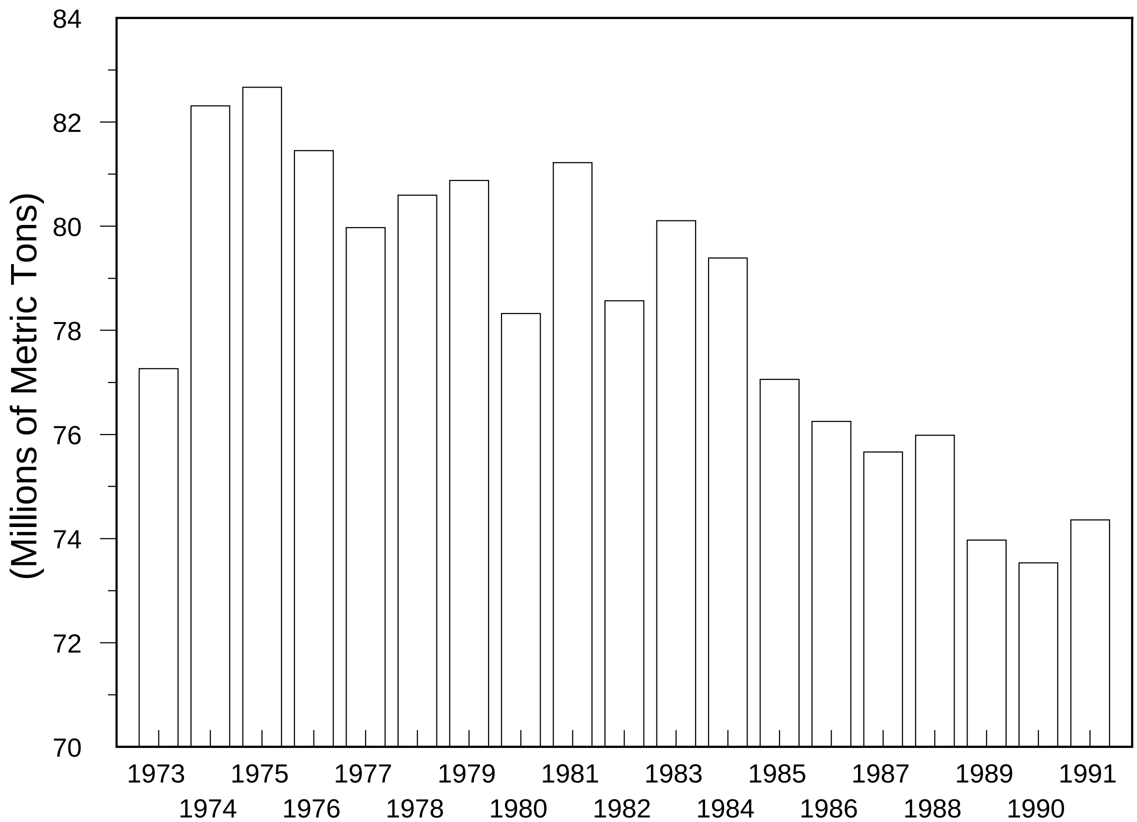
[12] Portland Cement Association, 1984. *U.S. Cement Industry - an Economic Report*, Skokie, Illinois. January 1984.

[13] U.S. Department of Commerce, Date Unknown. *Construction Materials Database*, Building Materials and Construction Division, Office of Forest Products and Domestic Construction, International Trade Administration, Washington, D.C.

[14] Portland Cement Association, 1992b, *op. cit.*

Exhibit 2-4

U.S. Clinker Capacity for the Period 1973-1991



Source: Portland Cement Association, 1992b, *op. cit.*

key exporters of cement to the U.S. Exports of U.S. cement are reported to have seldom exceeded 1 percent of total production. Not surprisingly, exports tend to occur when domestic market demand is low relative to foreign markets, and during domestic recessions.

2.2 CEMENT MANUFACTURING

This section provides a more detailed presentation of cement manufacturing, focusing on those aspects that influence the generation and characteristics of CKD. This section begins with a general description of the basic steps common to all cement production processes, followed by a comparison of the different kiln types that are in operation in the U.S., focusing on noteworthy operational differences and industry trends. The section concludes with a discussion of the inputs into the process of manufacturing cement (i.e., raw materials and fuels). The growing use of hazardous waste-derived fuels is an issue that is of growing importance not only to the regulatory status of CKD but to the larger issue of hazardous waste management in the United States.

2.2.1 The Basic Production Process

Although a variety of cement types are produced in the U.S., cement production generally follows a standard series of steps. The focus of this section is on the manufacture of

Portland cement, but the basic production steps are common to most other types as well. Portland cement is derived from a combination of calcium (usually in the form of limestone), silica, alumina, iron oxide, and small amounts of other materials. These raw materials are quarried, crushed, ground together, and then burned in rotary kilns at temperatures near 1,482°C (2,700°F). The resulting material (a mixture of marble- to fist-sized pellets and sand-sized particles) is called clinker. The clinker is finely ground into a gray powder and mixed with gypsum to slow down the "setting" (i.e., hardening) of the cement when it is used in concrete.[15] Manufacturers use clinker and specific additives in various proportions to create cements having different properties for specific construction applications. The general manufacturing steps are discussed below in greater detail and are presented schematically in Exhibit 2-5.

Typical Portland cement consists largely of limestone, clay and/or shale, and a small amount of gypsum and other minerals, such as iron ore, sand, or bauxite. Most of these mineral inputs into the production of cement are quarried on site, ground and blended, then fed into a kiln system. The type of Portland cement being produced determines the specific proportions of these raw materials. High levels of impurities in the raw feed may cause operational problems in the kiln, and/or produce inferior cement. A more detailed discussion of the differences in raw material types and composition and their effects is presented in Section 2.2.3.

Mining

Material mined for cement production consists primarily of limestone. Mining usually occurs in open quarries, although underground mining has been used in the past. During a typical surface mining operation, shovels or bulldozers remove overburden, rock is blasted, and front-end loaders or power shovels load the blasted rock into trucks or railroad cars.[16] The size of the mined rock is up to one meter in diameter. The rock is transported to the crushing plant located in the quarry or at the cement plant. Overburden, or waste rock, is often disposed on site in or adjacent to the quarry.[17] Overburden has also been used for riprap and fill material or sold as aggregate for concrete or road base use.[18]

Crushing

Once removed, the raw material (e.g., limestone) is crushed to a smaller size. The type of crusher used is dependent on the nature of the rock (e.g., hardness, lamination, and quarry product size). Common crusher types include: gyratory, jaw, and roll crushers and hammer and impact mills.

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[15] Portland Cement Association, 1984, *op. cit*.

[16] Not all quarries mine by blasting hard rock. In the Southeastern U.S., draglines are used to break up and load semi-consolidated material.

[17] Muelberg, P.E., *et al*., 1977. *Industrial Process Profiles for Environmental Use: Chapter 21, The Cement Industry*, U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati, Ohio. February 1977.

[18] Johnson, W., 1992. *Cement, Annual Report 1990*, U.S. Bureau of Mines, Washington, D.C. April 1992.

Exhibit 2-5

Steps in the Manufacture of Portland Cement

Exhibit 2-5 (continued)

Steps in the Manufacture of Portland Cement

Typically, a primary crusher reduces the rock from power shovel size to 0.1 to 0.25 meter (0.328 to 0.82 feet) in diameter and a secondary crusher reduces the product to 0.01 to 0.05 meters in diameter. This material is then conveyed with other raw materials to the grinding and blending step. Partial drying of rock is sometimes accomplished during the crushing process by passing furnace-heated air, clinker cooler exhaust air, or kiln exhaust gases through the crusher.[19,20]

Grinding and Blending

In general, during the grinding process crushed raw material is fed into the grinding mill, ground to a fine size range, and blended to obtain the correct composition for kiln feed. This material is commonly referred to as raw mix or raw meal. In the dry process, ground and blended materials are usually conveyed to a pre-drying step before being fed to the kiln. In the wet process, the raw materials are mixed with about 30 to 40 percent water during grinding or blending to form a well-homogenized slurry. Low concentrations of slurry thinners may be added, such as sodium carbonates, silicates, and phosphates, as well as lignosulfates and modified petrochemicals.[21,22]

Pre-Drying

In the dry process, raw materials must be dried before they are fed into the kiln. The moisture content of the ground raw materials is usually three to eight percent, but may reach 20 percent. Drying reduces moisture content to less than one percent. Ground stone is usually dried with furnace-heated air, clinker cooler exhaust air, or kiln exhaust gases in a cylindrical rotary dryer.[23]

Drying and Preheating

Within the kiln system, different chemical reactions and phase formations occur that are defined by specific temperature ranges of the feed material. Exhibit 2-6 shows the various reaction zones and the raw material temperatures in a typical rotary kiln.

The drying and preheating zone is where the first true thermal treatment occurs within the kiln system. In some kiln configurations (e.g., in wet kilns) this zone is located in the cool end of the kiln, while in others it resides in the preheater or precalciner. In any case, the following three sequential processes occur in this zone: evaporating all free water (material temperature 100°C); dehydrating clay minerals (material temperature beginning at 549°C); and increasing the feed temperature to the calcining temperature (material temperature 804°C).[24]

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[19] Sapp, J.E., 1981. *Energy and Materials Flows in the Cement Industry*, prepared for U.S. Department of Energy, June 1981.

[20] Muelberg, *et al*., 1977, *op. cit*.

[21] Sapp, 1981, *op. cit*.

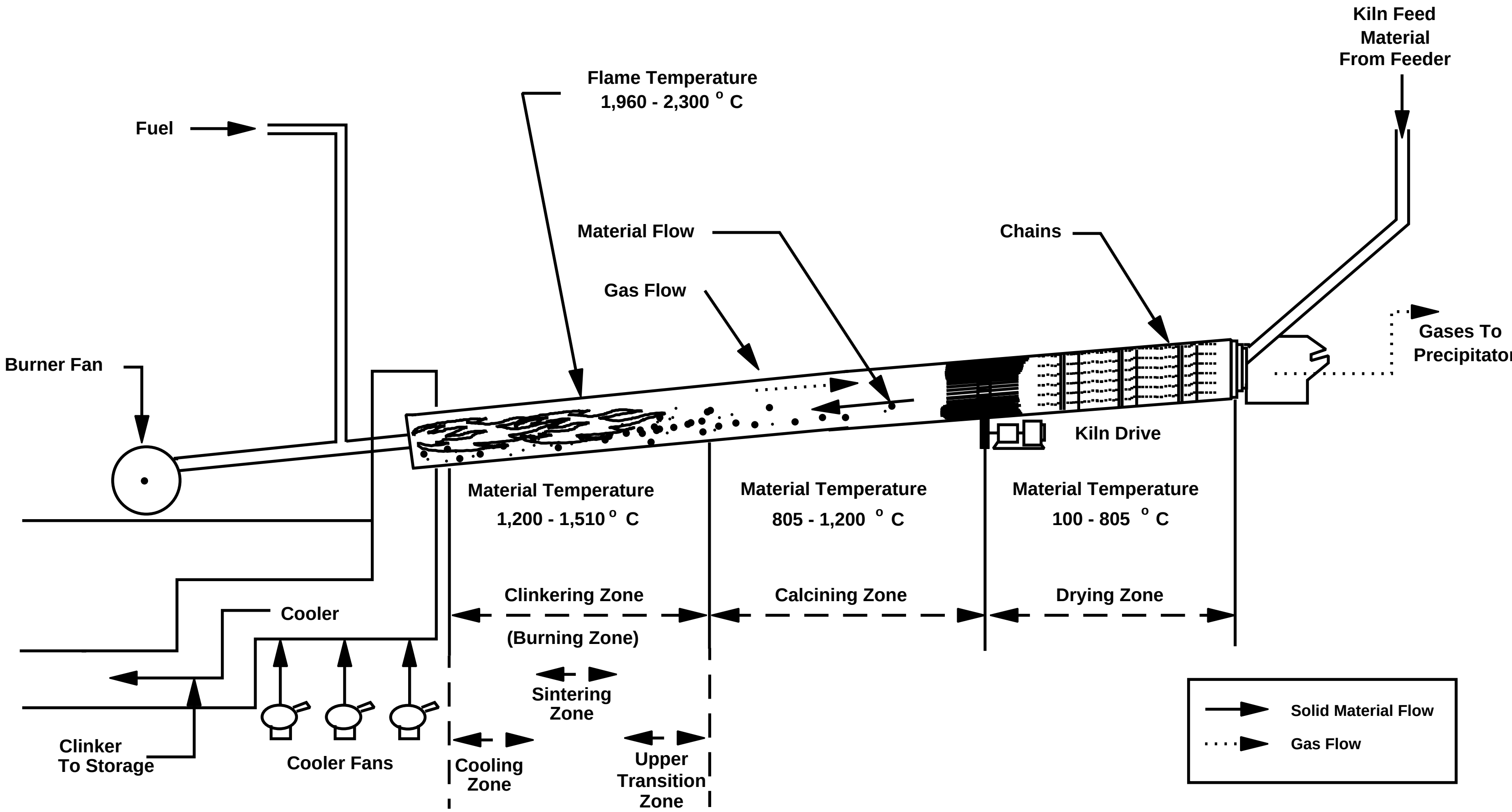
[22] Kirk-Othmer, 1979. Cement, *Kirk-Othmer Encyclopedia of Chemical Technology*, Volume 5, John Wiley and Sons, New York, New York.

[23] Muelberg, *et al*., 1977, *op. cit*.

[24] Peray, K.E., 1986. *The Rotary Cement Kiln*, Second Edition, Chemical Publishing Co., Inc., New York, New York.

Exhibit 2-6

Material Temperature Ranges in the Kiln Portion of the Cement Manufacturing Process



Calcining

Calcining, or calcination, is the process through which carbonates or other compounds are decomposed by application of heat. Carbon dioxide is driven off from limestone ($CaCO_3$) and magnesium carbonate ($MgCO_3$) contained in the feed, leaving free lime (CaO) and magnesia (MgO). This process occurs at a material temperature range between 804°C and 1,200°C.[25]

Complete calcination of the kiln feed before it enters the burning zone is essential to proper burning and clinker formation.[26] The successful calcining process, which produces a grayish-green clinker, requires the appropriate temperature and an oxidizing atmosphere to completely decompose the carbonates in the feed materials. Insufficient oxidizing conditions yield a brown clinker that produces an inferior cement.[27]

Burning

Though often used synonymously with the term sintering, the burning of the calcined kiln feed is actually a three-stage process occurring in the hot end of the kiln (refer to Exhibit 2-6). The area in which burning occurs can be divided into three sections: the upper transition zone, the sintering zone, and the cooling or lower transition zone. This production stage is also commonly referred to as clinkering, because passing through these zones results in the kiln feed becoming clinker. In the upper transition zone, interim-phase formations occur while some calcination is still being completed. The upper transition zone (material temperature range 1,200–1,400°C) is identified in a temperature profile by a rapid rise in material temperature just at the end of the calcining zone. The final stages of clinker compound formation take place in the sintering zone. This process involves exothermic reactions and is the zone of highest material temperature (1,400–1,510°C). The last 3.05 to 6.1 m of the kiln's discharge (hot) end constitute the cooling zone (material temperature range from a high of 1,510°C to a low of 1,290°C).[28]

Cooling

After leaving the kiln, the clinker is further cooled in rotary, planetary, or grate-type coolers by air pulled into the unit by dedicated cooler fans, and then transferred by conveyor to the finish mill.[29] The cooling process conditions can significantly influence the quality of the clinker. Generally, faster cooling rates result in a higher quality clinker.[30]

Finish Milling/Loading

At the finish milling stage, Portland cement is produced by grinding clinker together with about five percent gypsum to a fine powder (94 to 98 percent particles with diameters less than 0.044 millimeters). It is then loaded into bulk carriers or packaged into bags. The gypsum is added to retard the setting time of the cement, thereby making it more suitable for common

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25 *Ibid*.

26 *Ibid*.

27 Kohlhaas, B., *et al*., 1983. *Cement Engineers' Handbook*, Bauverlag GmbH, Wiesbaden and Berlin.

28 Muelberg, *et al*., 1977, *op. cit*. These units have been converted to ○C from ○F as reported.

29 *Ibid*.

30 Peray, 1986, *op. cit*.

construction applications. It is at this stage that various additives along with gypsum are introduced to create specialty Portland cements. For example, masonry cement production includes blending crushed limestone with the clinker and gypsum. Other typical finish milling additives include: blast furnace slag, fly ash, and natural pozzolans (such as volcanic rocks, diatomaceous earth, and burned oil shale residue).[31]

During the finish milling process, the proportioned materials are drawn up by belt conveyors to a two-compartment ball mill. A separator device recycles oversized products and sends correctly sized product to storage. To prevent dehydration of the gypsum, either air or water cooling is used during grinding.[32]

2.2.2 Kiln Design

Rotary cement kilns are horizontal, inclined rotating cylinders that are refractory lined, internally fired, and designed to produce clinker through the intense heating of raw materials. Raw materials are fed into the upper, cool end while fuels are normally fed into the lower, hot end. As a function of the inclined surface, combustion gases and raw materials move counterflow in kilns. Thus, the raw materials get progressively hotter as they travel down the length of the kiln to become clinker at the low, hot end. U.S. cement kilns range in length from 35.4 to 231.6 meters (m) (116 to 760 feet), and 2.4 to 7.3 m in diameter.[33]

Clinker is manufactured in five kiln types:

- Wet process;
- Dry process;
- Preheater;
- Precalciner; and
- Semidry process.

These kiln types represent variations on two primary cement kiln designs: wet process and dry process (preheater, precalciner, and semidry process kilns are variations on the standard dry process). Raw materials are generally the same for both wet and dry processes, but the sequences and operations for raw material crushing, grinding, and blending are different.[34] In both process types, the kiln generally slopes at an angle of about 3 degrees. Most kilns, both wet and dry, are equipped with a 18.3 to 30.5 m "chain" section in the upper, or cool end of the kiln, to increase the heat transfer rate from the discharge gas to the raw feed and to help keep the process material moving down the kiln. Chain sections also provide a

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[31] Kohlhaas, *et al*., 1983, *op. cit*.

[32] Muelberg, *et al*., 1977, *op. cit*.

[33] Johnson, W., 1992, *op. cit*.

[34] Beers, A., 1987. *Hazardous Waste Incineration: The Cement Kiln Option*, New York State Legislative Commission on Toxic Substances and Hazardous Wastes, Albany, New York. December 1987.

filtering action to reduce dust emissions.[35,36] Though the chains are expensive and require a high level of maintenance, the improved energy efficiency of the kiln justifies their use.[37,38]

One major difference between wet and dry kilns is the kiln length.[39] As described above and shown in Exhibit 2-6, the raw material travels through several reaction zones before becoming clinker. The number of these zones required and their relative length varies by kiln type. Wet process kilns require additional length for preheating the slurry feed. To obtain the necessary heat transfer for water evaporation, wet kilns must be long, typically ranging from 137 to over 183 m in length.[40,41] Dry process kilns do not require this slurry preheat zone, and require about 10 percent less length for evaporation.[42] Therefore, standard dry process kilns may be somewhat shorter than otherwise comparable wet kilns. The preheater, precalciner, and semidry process kilns have only calcining and burning zones, because the material has been dried before it enters the kiln. Accordingly, these kiln types may in some cases be very short (under 61 m).[43,44] Therefore, in general, dry kiln types tend to be shorter than wet kilns of the same production capacity (i.e., their length to capacity ratio is smaller). As a result, the use of dry kiln technology has allowed the construction of higher capacity kilns. For example, precalciner kilns in operation in Japan reportedly produce over 9,072 metric tons of clinker per day,[45] while the largest U.S. clinker capacity for a preheater/precalciner kiln is 4,700 metric tons per day.[46] By comparison, available data indicate that the largest wet kilns in the U.S. have a capacity of approximately 3,630 metric tons per day.

Another major difference between wet and dry processes is evident in their heat requirements.[47] At any given location in a kiln, the gas temperature always exceeds the material temperature. However, the closer that these two temperatures approach one another, the more efficient the heat exchange between the gases and the material. Each of the five kiln types has a characteristic temperature profile. In dry kilns, gas and material temperatures tend

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[35] Muelberg, *et al*., 1977, *op*. *cit*.

[36] Engineering-Science, 1987. *Background Information Document for the Development of Regulations to Control the Burning of Hazardous Wastes in Boilers and Industrial Furnaces, Volume II: Industrial Furnaces*, submitted to U.S. Environmental Protection Agency, Waste Treatment Branch, Washington, D.C. January 1987.

[37] Peray, 1986, *op*. *cit*.

[38] Muelberg, *et al*., 1977, *op*. *cit*.

[39] Engineering-Science, 1987, *op. cit.*

[40] Engineering Science, 1987, *op. cit.*

[41] Johnson, 1992, *op. cit.*

[42] Peray, 1986, *op. cit.*

[43] Engineering Science, 1987, *op*. *cit*.

[44] Johnson, 1992, *op. cit.*

[45] Kirk-Othmer, 1979, *op. cit.*

[46] Portland Cement Association, 1992b, *op. cit.*

[47] Engineering Science, 1987, *op*. *cit*.

to be much closer over the entire length of this profile than in wet kilns.[48] Therefore, dry kilns tend to be more efficient than wet kilns, requiring less energy input per ton of clinker produced. Exhibit 2-7 presents reported typical energy requirements for various kiln types.

Exhibit 2-7

Typical Energy Requirements for Each Kiln Type[a]

Kiln Type	Energy Required (Kcal/kg output)
Wet Process Kiln	1,529 – 1,668
Dry Process Kiln	1,251 – 1,390
Semidry (Lepol) Kiln	945.2
Preheater Kiln	750.6 – 889.6
Precalciner Kiln	Unknown[b]

[a] Energy requirements provided in this exhibit are those reported in the literature. Average energy requirements calculated from facility responses to the 1991 PCA survey are comparable. The sample of 46 wet kilns for which complete information was provided averaged 1,520.7 Kcal/kg (5.47 million Btus). The sample of 83 dry kilns, including semidry, preheater, and precalciner kilns, averaged 1,175.9 Kcal/kg.

[b] Specific data were not available for precalciner kilns. However, while precalciners burn 30-50 percent of their total energy input at the rear of the kiln, reducing the heat load on the burning zone, preheater and precalciner kilns consume approximately the same amounts of fuel. Therefore, while precalciners reduce the heat requirements of the kiln itself, it is believed that the total heat required for the complete process (calcination through clinker production) is unchanged and similar to that required for a typical preheater kiln.

Sources: Engineering Science, 1987, *op. cit.*; Perry's Chemical Engineers' Handbook, 1984. Sixth Edition, McGraw-Hill, New York, New York.

The specific characteristics of the five kiln types are discussed below in more detail.

Wet Process Kiln

In the wet process, the limestone and other raw mix components are ground wet and slurried at a moisture content of 30 to 40 percent. This slurry is fed into the upper, or cool, end of the kiln and flows down slope through the kiln to the hot discharge end. A typical process flow diagram for a wet process kiln is presented in Exhibit 2-8. Wet process kilns are longer than dry process kilns because a substantial portion of the kiln length (20 to 25 percent) must be used for evaporation of the slurry water.[49,50]

When compared to dry process kilns, reported advantages of wet process kilns include more uniform feed blending, generally lower emissions of kiln dust, and compatibility with moist climates where complete drying of raw feed is difficult to achieve.[51,52] The primary disadvantage

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[48] Peray, 1986, *op. cit.*

[49] Muelberg, *et al.*, 1977, *op. cit.*

[50] Engineering Science, 1987, *op. cit.*

[51] Peray, 1986, *op. cit.*

[52] Beers, 1987, *op. cit.*

associated with wet process kilns, however, is that they require significantly more energy, because large quantities of water must be evaporated from the raw feed, resulting in higher operational costs. Typical energy requirements for wet process kilns range from 1,529 to 1,668 Kcal/kg of clinker produced.[53,54]

Dry Process Kiln

In the dry process, dry raw mix is pneumatically pumped to the upper end of the kiln. The meal flows down through the sloped kiln as it is thermally treated. Dry process kilns have diameters similar to wet process kilns, but are shorter because there is no evaporation zone required. Dry process kilns operate with a high exit gas temperature of approximately 450°C (840°F), and typically, employ water sprays to cool the gas before it enters the dust control equipment.[55]

Kiln gases exiting dry process kilns do not pass through a wet raw mix that would significantly decrease exit gas temperatures. The high exit gas temperatures can therefore be used for cogeneration of electrical power. This fact may be significant to existing dry process plants because cogeneration could be energy-conserving. In some locations it may even be more economical to add a power plant to an existing dry kiln than to retrofit the kiln with a preheater.[56] The number of facilities currently coupled with power plant operations is not presented in the literature. In the absence of cogeneration equipment, the hot exit gas is used as supplemental combustion air for the kiln fuel.[57]

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[53] Engineering Science, 1987, *op. cit.*

[54] Perry's Chemical Engineers' Handbook, 1984, *op. cit.*

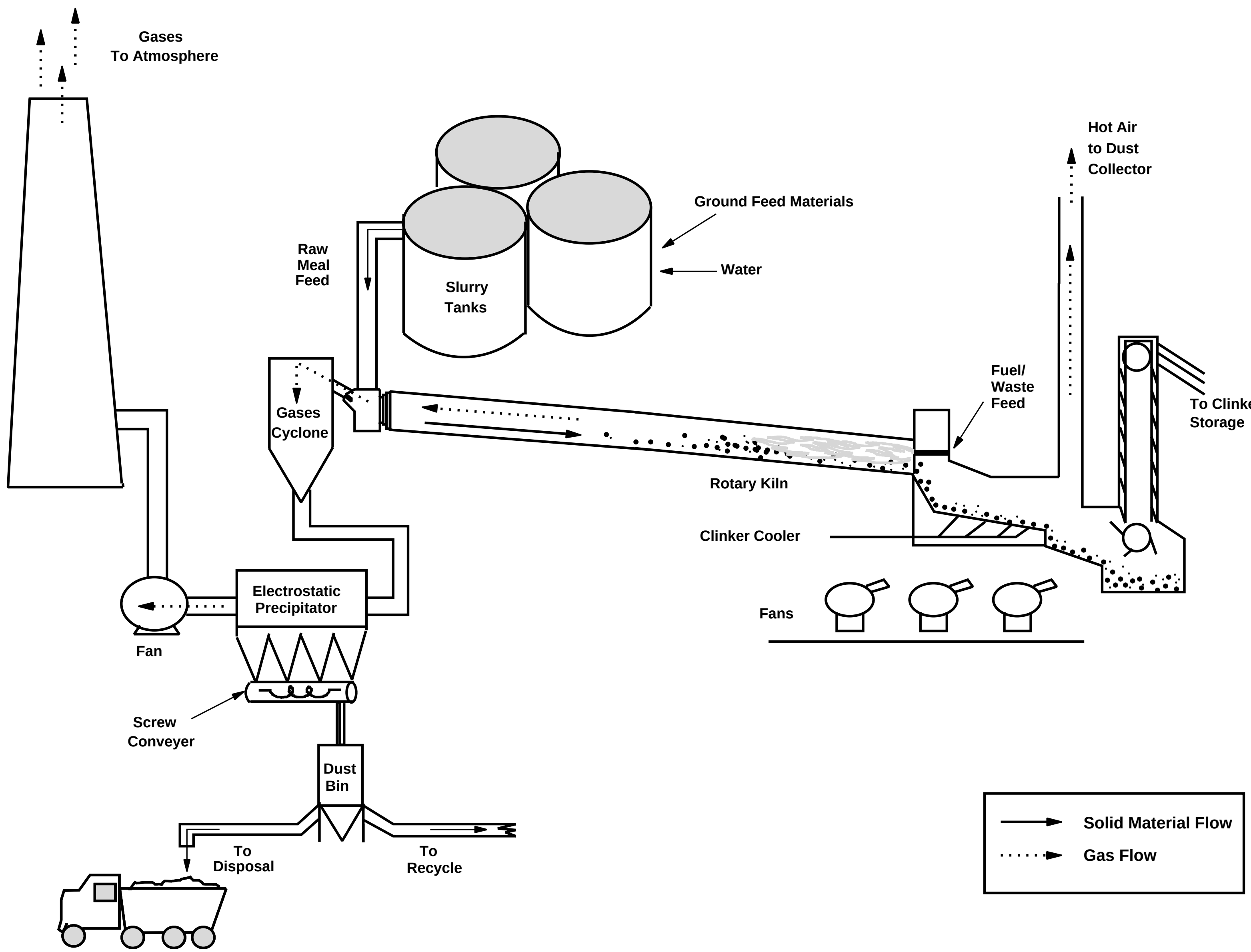
[55] Peray, 1986, *op. cit.*

[56] *Ibid.*

[57] Muelberg, *et al.*, 1977, *op. cit.*

Exhibit 2-8

Typical Process Flow Diagram for a Wet Process Cement Kiln



Increased energy efficiency is a major advantage of dry process kilns in comparison to wet process kilns. Available data indicate that dry kilns are approximately 10-25 percent more thermally efficient than wet kilns, requiring 1,251 to 1,390 Kcal/kg of clinker produced.[58,59]

Preheater Kiln

Preheater kilns, more accurately referred to as suspension preheater kilns, preheat and partially calcine raw meal by passing it through a system of heat exchange cyclones before it enters the kiln.[60,61] A typical, four-stage suspension flash preheater kiln is illustrated in Exhibit 2-9. As the raw material passes through each of the four stages, it gets hotter and becomes more processed before entering the kiln, resulting in more uniformly processed material. Suspension preheaters reduce by one half to two thirds the required kiln length of the rotary dry process kilns they precede. Because of the increasing fuel costs experienced by kiln operators during the 1970's and early 1980's, suspension preheaters came into common use.[62]

Suspension preheater kilns are the most energy-efficient types of kilns available, producing clinker at energy consumption rates ranging from 750.6 to 889.6 Kcal/kg.[63,64] The addition of a preheater with or without a precalciner improves process efficiency, through fuel savings and scale economies associated with larger production units.[65] The feed in precalciner and preheater kilns also tends to be much more uniformly calcined than in dry kilns and even in longer wet kilns. Operating conditions in the precalciner and preheater kilns are also easier to control.[66]

One disadvantage of the preheater kiln is that plug-up problems can occur at the lower cyclone stage and kiln inlet due to high concentrations of volatile constituents such as alkalies, sulfur, and chlorides in the kiln exit gases. To reduce the severity of this problem, alkali and sulfur bypass systems allow evacuation of some of the kiln exit gases before they reach the preheater cyclones.[67]

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[58] Engineering-Science, 1987, *op. cit.*

[59] Perry's Chemical Engineer's Handbook, 1984, *op. cit.*

[60] Peray, 1986, *op. cit.*

[61] Muelberg, *et al.*, 1977, *op. cit.*

[62] Peray, 1986, *op. cit.*

[63] Engineering Science, 1987, *op. cit.*

[64] Perry's Chemical Engineers' Handbook, 1984, *op. cit.* The units were converted to Kcal/kg from million Btus/ton as reported.

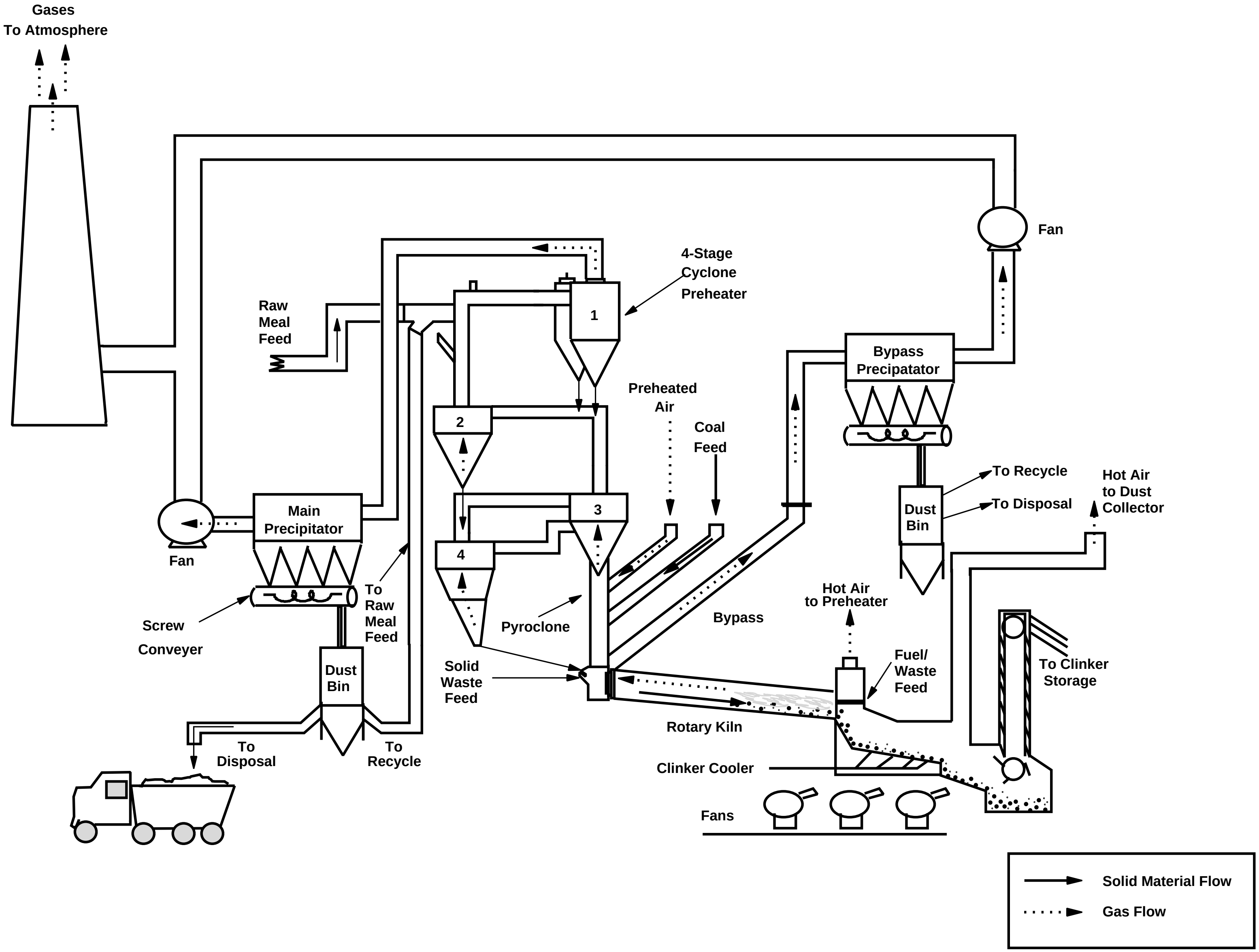
[65] Engineering-Science, 1987, *op. cit.*

[66] Peray, 1986, *op. cit.*

[67] *Ibid.*

Exhibit 2-9

Typical Process Flow Diagram for a Suspension Flash Preheater Cement Kiln



Precalciner Kiln

Precalciner kilns, the most recent advance in cement manufacturing technology, are essentially suspension preheater kilns that are equipped with a secondary firing system (flash furnace) attached to the lower stage of the preheater tower. A pyroclone precalciner kiln is illustrated in Exhibit 2-10. Precalciner kilns fall into two categories -- kilns with and kilns without tertiary air ducts. Kilns with tertiary air ducts are supplied with air from the exhaust gases from the clinker cooler. Precalciner kilns without tertiary air ducts receive air from the kiln itself. The kilns with tertiary air ducts are generally more difficult to control.[68] Both categories process the raw feed similarly.

Precalciner and preheater kilns have several advantages over conventional dry and wet long kilns. As mentioned above, the feed in precalciner and preheater kilns is much more uniformly calcined than in conventional dry and wet long kilns. Operating conditions in the precalciner and preheater kilns are also easier to control. Moreover, precalciner kilns greatly reduce the residence time needed for raw material to become clinker. A conventional dry kiln, for example, requires approximately 45.7 m to achieve 90 percent calcination, a distance that takes the feed about one hour to traverse. The precalciner kiln, in contrast, completes the same amount of thermal work in less than a minute. Precalciners do not improve the energy efficiency of the calcining process, but they do reduce the required heat load in the rotary kiln, thereby extending refractory service life, and reducing operational costs. Additionally, less expensive, lower grade fuels, such as subbituminous coal, lignite, and oil shale, as well as tires and waste oil, can be burned in the auxiliary firing unit, reducing the fuel cost per unit of clinker. Precalciner kilns also exhibit output rates that were previously considered unattainable.[69]

The addition of a preheater or precalciner significantly improves the overall energy efficiency of the cement production process. Depending on whether a preheater and/or precalciner is used, dry process plants can have a long, medium, or short kiln.[70]

Semidry Process Kiln

The semidry process kiln, also known as the "grate process" or the "Lepol" kiln, is a type of preheater kiln that begins with raw feed nodules containing 10 to 15 percent moisture. In the semidry process, raw material nodules travel on a grate through a preheater in which they are partially calcined. The partly calcined material then falls down a chute into the rotary kiln where the final clinkering takes place. The partial precalcination allows the rotary kiln to be only about one-third the usual length. This type of kiln usually requires additional labor to monitor the thickness of the feed bed and to oversee production of the nodules, which is not required in operating conventional rotary kilns. Some plants use filter press cakes rather than nodules for kiln feed. In these cases, the wet-feed slurry is passed through large presses to remove free water, and more importantly, to remove alkalies before the cakes are fed to the kiln.[71]

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[68] *Ibid*.

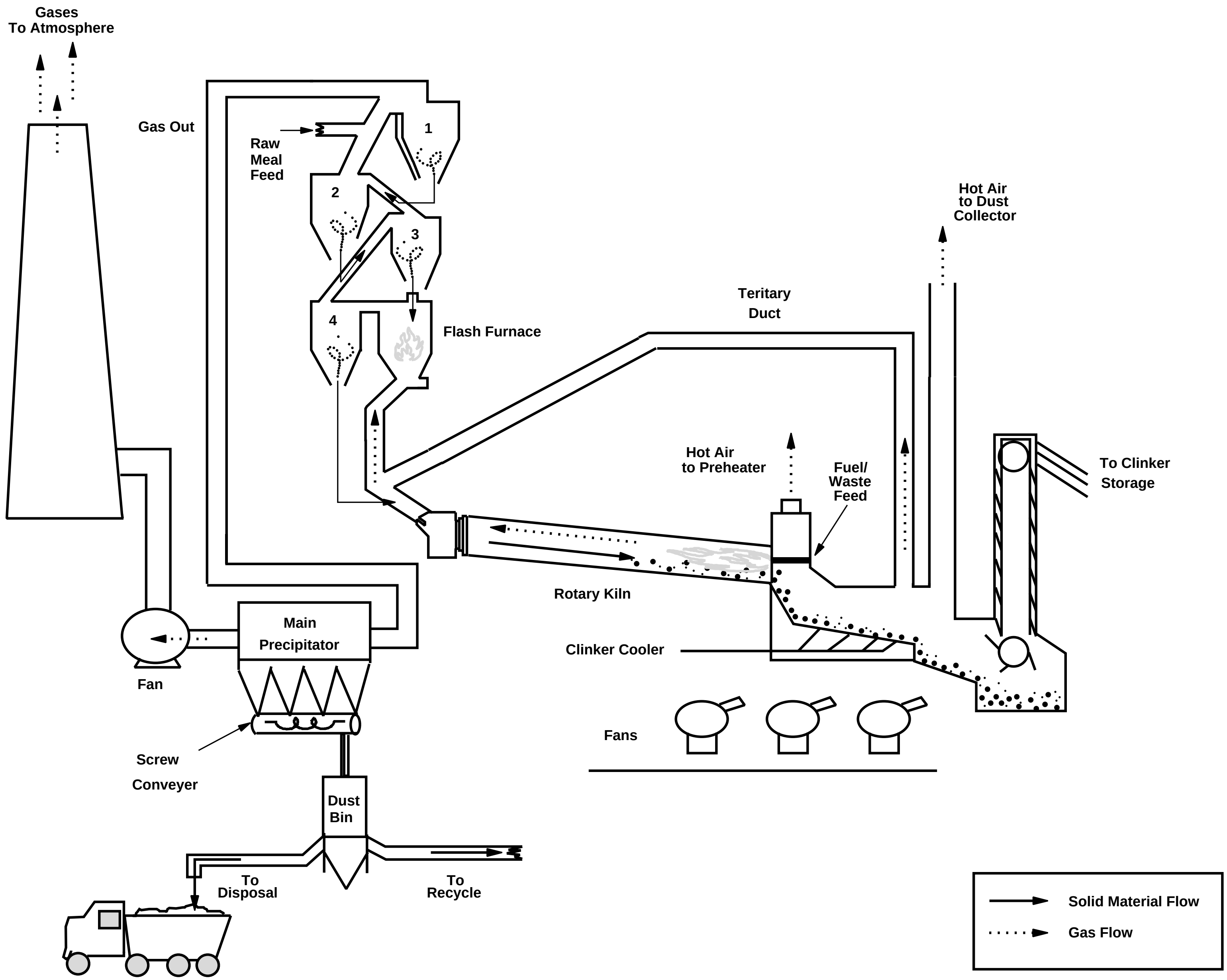
[69] *Ibid*.

[70] Engineering Science, 1987, *op. cit*.

[71] Peray, 1986, *op. cit*.

Exhibit 2-10

Typical Process Flow Diagram for a Precalciner Coal and Waste Fired Cement Kiln



Although nearly as energy efficient as preheater and precalciner kilns, the semidry process kiln has a limited output capacity. The semidry process is practical, however, in geographic areas where raw material moisture is so high that it cannot be economically removed by waste heat from the kiln. An additional advantage is that the semidry process kiln operates with much lower dust content in the waste gases than preheater and precalciner kilns.[72] In 1990, however, only four of 115 domestic cement plants reported using a semi-dry process kiln system. The small number of these kilns operating in the U.S. is believed to be related to low output rates and the labor intensive nature of this process.

Trends in Kiln Technology and Use

Exhibit 2-11 shows the age distribution of kilns both in terms of numbers and capacity. Clearly, there has been a trend over the years toward larger capacity kilns of both basic types. While the earliest domestic facilities produced Portland cement by the wet process, the dry process also has been utilized for some time. From the 1950's through the 1970's, wet process kilns remained competitive with the more energy-efficient dry kilns because they were less labor-intensive than dry

Exhibit 2-11

Age and Capacity of Existing Kilns

Date of Kiln Installation	Wet Kilns		Dry Kilns		Overall	
	Number of Kilns	Average Capacity (Ktons)	Number of Kilns	Average Capacity (Ktons)	Number of Kilns	Average Capacity (Ktons)
After 1980	0	0.0	26	690.3	26	690.3
1976-1980	0	0.0	18	653.1	18	653.1
1971-1975	11	459.6	32	476.8	43	470.9
1966-1970	13	424.9	19	425.0	32	426.9
1961-1965	20	355.4	38	336.1	58	346.3
1956-1960	19	260.5	46	199.6	65	226.7
1951-1955	5	193.6	19	176.6	24	181.1
1946-1950	6	158.0	9	164.0	15	160.0
1941-1945	1	150.0	0	0.0	1	150.0
1936-1940	1	153.0	2	138.0	3	143.0
1931-1935	0	0.0	0	0.0	0	0.0
Before 1931	4	159.3	0	0.0	4	159.3

Source: Adapted from Portland Cement Association, 1992b, *op. cit.*

kilns.[73] However, no new wet kilns have been constructed since 1975. This change to more energy-efficient dry technologies may be attributed to rising energy prices. Because dry kilns can be constructed with larger capacities than wet kilns, the trend toward larger capacities also may have made this technology more attractive because of positive economies of scale.

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[72] *Ibid.*

[73] Kirk-Othmer, 1979, *op. cit.*

Kilns normally operate 24 hours/day and 7 days/week, but temporary shutdowns for refractory relining and other maintenance activities reduce the effective annual operating period substantially. The most recent figures report the average annual operating time at 313 days/year as of 1990. Although the kilns operate nearly year round, they do not necessarily operate at maximum capacity at all times. The portion of capacity utilized depends upon market factors. As indicated in the preceding discussion of industry structure, annual clinker capacity utilization is approximately 86 percent.[74]

2.2.3 Process Inputs

Many of the issues surrounding CKD focus on the health and environmental impacts associated with exposure to CKD or its constituents,[75] and on the development of technologies to improve recovery rates, minimize generation, improve operational efficiencies in existing kiln systems, and seek alternative beneficial applications for existing, stockpiled CKD. An understanding of these issues requires knowledge of both the raw materials and the fuels used in cement kiln systems, because it is these inputs, coupled with the manufacturing process, that to a large extent, determine the characteristics and quantities of CKD generated.

The following discussion provides insight into how the inputs into the process of manufacturing Portland cement can affect process operations and the ultimate composition and fate of CKD. The focus is on the major (bulk) constituents of raw mix and fuel inputs. A detailed discussion of trace constituents and their sources, fate, and impacts is presented in Chapters 3, 5, and 7.

The data used in this section of the report were taken from facility responses to the 1991 PCA survey; however, not all domestic facilities responded to this survey. For example, the totals for raw material and fuel consumption reported here do not reflect total consumption for the industry. Rather, they reflect consumption for the <u>sample</u> of facilities that responded to the pertinent questions in the survey. EPA has no reason to believe that these facilities are not representative of the population at large, and has conducted the analyses presented in this report accordingly. In addition, the sample of facilities providing information for 1990 in the survey was not necessarily the same as the sample providing information for 1985. Therefore, the reader should not compare or make any inferences regarding total consumption for these two years.

Raw (Feed) Materials

Portland cement is commonly made from a mixture of calcareous (calcium containing) materials, typically limestone, and smaller amounts of materials that contain silica, alumina, and iron. Kiln feed is generally comprised of about 80 percent carbonate of lime and about 20 percent silica with much lower quantities of alumina and iron. The number of raw materials required to achieve this blend depends on the composition of the materials and their availability.[76] Exhibits 2-12, 2-13, and 2-14 show the types of raw materials consumed and the types of feed mixtures used in 1990 and 1985 at facilities that responded to the 1991 PCA survey.[77] There has been very little change in the types of materials used for cement manufacture over the last five years. Limestone is the primary source of calcium for nearly all cement plants, though one facility reported using cement rock (a type of limestone that is nearly

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[74] Johnson, W., 1992, *op. cit.*

[75] Exposure to CKD can be direct or through the contamination of environmental media such as ground water.

[76] Peray, 1986, *op. cit.*

[77] For more detailed information on the derivation of the raw material consumption statistics used in this report, refer to the Technical Background Document.

perfectly balanced for cement manufacture) in 1990, and one facility reported using marl (an earthy material containing significant amounts of calcium carbonate). In the past, plants in Alabama and Arkansas have used chalk, and plants along the Gulf of Mexico and the coast of California have used crushed coquinoid limestone (often referred to as shell hash) as sources of calcium.[78] However, no facilities reported using these materials in the 1991 PCA survey.

Shale, clay, and sand are the primary materials fed as sources of silica and alumina. Some facilities also utilize ash (typically fly ash or bottom ash) as a primary or secondary feed for its silica and alumina content. A majority of facilities use either iron ore or steel mill scale to supplement the iron content of their mix. Other materials used in significant amounts in cement kilns include the following: gypsum, for its calcium content; bauxite, an aluminum ore; diatomaceous earth, which is high in silica; and slag, for its silica and calcium content. Exhibit 2-15 presents chemical composition data for several types of limestone and many of these other feed materials.

In addition to the chemical composition of the desired product, the proportion of each type of raw material used in a given cement kiln will depend on the composition of the specific materials available to the operator. Exhibit 2-16 shows the quantity ranges and typical mixtures of materials fed to kilns in 1990. The specific blend of materials used at a given kiln at a given time is often calculated through an iterative process using computer programs. The proportioning process takes into account the ratios of calcium, silica, alumina, and iron needed to produce good quality clinker, as well as the "burnability" of the raw mix (i.e., the requirements in terms of time, temperature, and fuel to process the material).[79] In addition, kiln operators pay close attention to the presence of "impurities" in the mixture, including magnesia, sulfur, chlorides, and oxides of potassium and sodium (referred to as "alkalies"). Magnesia (MgO) levels are carefully monitored because they can lead to the production of clinker that is unsound if not cooled rapidly (i.e., such clinker used to make concrete can cause destructive expansion of hardened concrete through slow reaction with water).[80] Magnesia can, however, be desirable to some extent because it acts as a flux at sintering temperatures, facilitating the burning process. Alkalies can react in the cool end of the kiln with sulfur dioxide, chlorides, and carbon dioxide contained in the kiln gas and can lead to operational problems. Therefore, high levels of alkalies, sulfur, and chlorides in the feed mix are undesirable.[81]

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[78] Boynton, R.S., 1980. *Chemistry and Technology of Lime and Limestone*, Second Edition, John Wiley and Sons, New York, New York.

[79] Kirk-Othmer, 1979, *op. cit.*

[80] Taylor, H.F.W., 1990. *Cement Chemistry*, Academic Press Inc., San Diego, California.

[81] Peray, 1986, *op. cit.*

Exhibit 2-12

Feed Mixtures in 1990

Primary Feed(s)[a]	Number of Plants[b]	Secondary Feeds[c] (Number of Plants Utilizing)							Other Secondary Feeds
		Sand	Shale	Clay	Iron Ore	Ash[d]	Mill Scale	Gypsum	
Limestone	19	12	5	7	15	3	3	3	Electroplating Sludge, Filter Cake, Slag, Bauxite
Limestone and Clay	16	7	1	--	7	3	3	2	Foundry Wastes, Spent Catalysts, Carbon Black
Limestone and Shale	14	9	--	0	2	2	0	2	
Limestone and Sand	10	--	2	1	6	1	2	2	Bauxite, Iron Flue Dust, Mag Rock
Limestone and Ash[e]	6	2	0	2	3	--	1	1	Staurolite
Limestone, Sand, and Shale	5	--	--	1	4	0	1	0	
Limestone, Sand, and Clay	4	--	0	--	2	1	1	0	Slag, Aluminum Silicate
Other[f]	5	2	2	1	5	0	0	0	
Total	**79**	**32**	**10**	**12**	**44**	**10**	**11**	**10**	

[a] For purposes of this analysis, primary feeds are defined as those materials that make up five percent or more of the total feed.

[b] This exhibit presents information only for the 79 facilities for which 1990 raw feed information was available.

[c] For purposes of this analysis, secondary feeds are those materials that make up less than five percent of the total feed.

[d] Includes bottom ash, fly ash, and alumina ash (calcined alumina).

[e] Includes facilities for which the primary feeds were limestone and ash; limestone, ash, and sand; limestone, ash, and clay; and limestone, ash, and slag.

[f] Other primary feed mixtures in 1990 included: limestone, shale, and clay; limestone and gypsum; limestone, shale, and diatomaceous earth; cement rock and limestone; and marl and limestone.

Source: Facility responses to the 1991 PCA Survey.

Exhibit 2-13

Feed Mixtures in 1985

Primary Feed(s)[a]	Number of Plants[b]	Secondary Feeds[c] (Number of Plants Utilizing)							Other Secondary Feeds
		Sand	Shale	Clay	Iron Ore	Ash[d]	Mill Scale	Gypsum	
Limestone	26	18	7	7	19	2	4	4	Slag, Bauxite, Dolomite
Limestone and Clay	15	3	0	--	6	3	3	2	Slag, Fluorspar, Calcium Chloride, Carbon Black
Limestone and Shale	10	5	--	0	6	0	0	1	
Limestone and Sand	5	--	1	2	2	1	0	0	Iron Flue Dust
Limestone and Ash[e]	5	4	0	1	2	--	2	0	Staurolite
Limestone, Sand, and Shale	5	--	--	0	3	1	1	0	
Limestone, Sand, and Clay	5	--	0	--	4	2	1	0	
Other[f]	5	3	3	2	4	0	0	0	
Total	**76**	**33**	**11**	**12**	**46**	**9**	**11**	**7**	

[a] For purposes of this analysis, primary feeds are defined as those materials that make up five percent or more of the total feed.

[b] This exhibit presents information only for the 76 facilities for which 1985 raw feed information was available.

[c] For purposes of this analysis, secondary feeds are those materials that make up less than five percent of the total feed.

[d] Includes bottom ash, fly ash, and alumina ash.

[e] Includes facilities for which the primary feeds were limestone and ash; limestone, ash, and clay; and limestone, ash, and slag.

[f] Other primary feed mixtures in 1985 included: limestone, shale, and clay; limestone, shale, and diatomaceous earth; marl and limestone; limestone, sand, shale, and clay; and limestone, sand, and mag rock (limestone with high magnesium content).

Source: Facility responses to the 1991 PCA Survey.

Exhibit 2-14

Raw Material Consumption in 1990 and 1985[d]

Feed Material	1990 Consumption[a]		1985 Consumption[b]	
	Metric Tons	Percent of Total	Metric Tons	Percent of Total
Limestone	67,852,083	84.28	60,359,409	85.55
Shale	3,685,150	4.58	3,215,690	4.56
Clay	2,989,094	3.71	3,098,777	4.39
Sand	2,076,220	2.58	1,475,413	2.09
Marl	1,526,864	1.90	644,430	0.91
Ash[c]	1,158,200	1.44	743,550	1.05
Iron Ore	512,659	0.64	451,471	0.64
Gypsum	321,122	0.40	149,674	0.21
Bauxite	89,280	0.11	36,320	0.05
Mill Scale	76,623	0.10	87,442	0.12
Diatomaceous Earth	74,386	0.09	81,013	0.11
Slag	57,580	0.07	134,286	0.19
Mag Rock	9,980	0.01	56,065	0.08
Other	80,875	0.10	20,241	0.03
Total	**80,510,116**	**100.00**	**70,553,781**	**100.00**

[a] Reflects 1990 raw material consumption for the 79 facilities for which data were available.

[b] Reflects 1985 raw material consumption for the 76 facilities for which data were available.

[c] Includes bottom ash, fly ash, and alumina ash.

[d] These numbers have been converted from short tons per year as reported in the source.

Source: Facility responses to the 1991 PCA survey.

Exhibit 2-15
Typical Composition of Raw Materials

Feed Material	Constituent (weight percent)					Ignition Loss (weight percent)
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	
CALCIUM SOURCES						
Indiana high calcium limestone	54.5	0.7	0.7	0.1	0.6	40 - 43
Virginia high calcium limestone	55.3	0.4	0.1	0.1	0.5	40 - 43
Kansas cretaceous high calcium limestone (chalk)	52.5	2.4	1.6	0.6	0.6	40 - 43
Illinois Niagaran dolomitic limestone	31.2	0.1	0.3	0.2	20.5	44
Northwestern Ohio Niagaran dolomitic limestone	29.5	0.1	0.0	0.1	21.1	44
New York magnesian limestone	45.7	2.6	0.2	0.2	7.1	44
Lehigh Valley, Pennsylvania limestone (cement rock)	38.9	19.8	5.4	1.6	2.7	32 - 37
Pennsylvania limestone (cement rock)	41.8	13.4	4.6	0.6	1.9	32 - 37
Marl	49.1	6.0	0.6	2.3	0.4	40.4
SILICA AND ALUMINA SOURCES						
Shale	3.2	53.8	18.9	7.7	2.2	8.2 - 13.1
Clay	0.5-0.9	61.0-67.8	14.3-16.9	4.5-12.4	0.4-1.2	8
Sand	0.8	70.0	15.0	5.0	0.2	8.6
Blast Furnace Slag	35.5	33.1	9.1	0.9	16.4	2.1
Bauxite	--	10.6	57.5	2.6	--	28.4
IRON SOURCES						
Iron Ore	--	6.7	1.4	89.7	0.4	0.2
Steel Mill Scale	--	2.5	1.1	89.9	--	4.0

Sources: Boynton, 1980, *op. cit.*; Peray, 1986, *op. cit.*; Kirk-Othmer, 1979, *op. cit.*

Exhibit 2-16

Typical Feed Mixtures in 1990

Primary Feed(s)		Feed Composition (weight percent)								
		Limestone	Sand	Shale	Clay	Iron Ore	Ash[a]	Mill Scale	Gypsum	Other
Limestone	Range	89.67 - 99.14	0.00 - 3.76	0.00 - 4.40	0.00 - 4.41	0.00 - 2.77	0.00 - 4.80	0.00 - 0.72	0.00 - 3.58	0.00 - 3.27
	Average	95.05	1.29	0.63	0.76	1.11	0.29	0.08	0.36	0.44
Limestone and Clay	Range	74.54 - 91.10	0.00 - 4.91	0.00 - 3.16	6.95 - 22.67	0.00 - 0.78	0.00 - 4.29	0.00 - 1.66	0.00 - 2.28	0.00 - 1.95
	Average	83.08	1.08	0.19	14.54	0.16	0.43	0.18	0.15	0.19
Limestone and Shale	Range	69.27 - 91.98	0.00 - 4.60	5.01 - 30.73	0.00 - 0.00	0.00 - 1.44	0.00 - 2.85	0.00 - 0.00	0.00 - 3.00	0.00 - 0.39
	Average	82.48	1.37	15.18	0.00	0.38	0.22	0.00	0.35	0.03
Limestone and Sand	Range	80.52 - 93.89	5.10 - 17.68	0.00 - 4.29	0.00 - 2.63	0.00 - 2.24	0.00 - 1.61	0.00 - 0.72	0.00 - 2.56	0.00 - 0.00
	Average	88.85	8.09	0.76	0.26	0.64	0.16	0.14	0.27	0.00
Limestone and Ash[b]	Range	77.58 - 91.4	0.00 - 10.32	0.00 - 0.00	0.00 - 13.04	0.00 - 1.24	8.21 - 13.27	0.00 - 0.25	0.00 - 0.00	0.00 - 0.00
	Average	83.69	2.87	0.00	2.88	0.50	10.01	0.05	0.00	0.00
Limestone, Sand, and Shale	Range	78.47 - 83.58	5.68 - 9.36	7.86 - 11.61	0.00 - 1.53	0.00 - 2.36	0.00 - 0.00	0.00 - 0.07	0.00 - 0.00	0.00 - 0.00
	Average	81.18	7.40	9.94	0.31	1.16	0.00	0.01	0.00	0.00
Limestone, Sand, and Clay	Range	75.76 - 82.93	5.77 - 9.71	0.00 - 0.00	5.37 - 14.86	0.00 - 1.99	0.00 - 1.20	0.00 - 2.25	0.00 - 0.00	0.00 - 3.62
	Average	80.27	8.28	0.00	8.80	0.89	0.30	0.56	0.00	0.91
Range of Above		**69.27 - 99.14**	**0.00 - 17.68**	**0.00-30.73**	**0.00-22.67**	**0.00-2.77**	**0.00-13.27**	**0.00-2.25**	**0.00-3.58**	**0.00-3.62**
All Facilities[c]	**Range**	**19.85 - 99.14**	**0.00-17.68**	**0.00-30.73**	**0.00-22.67**	**0.00-2.77**	**0.00-13.27**	**0.00-2.25**	**0.00-10.42**	**0.00-3.62**
	Average	**84.98**	**2.90**	**3.89**	**3.93**	**0.63**	**0.96**	**0.11**	**0.35**	**0.19**

[a] Includes bottom ash, fly ash, and alumina ash.

[b] Includes facilities whose primary feeds were limestone and ash; limestone, ash, and sand; limestone, ash, and clay; and limestone, ash, and slag.

[c] Reflects feed mixtures for the 79 facilities for which data were available and includes facilities that do not fall into one of the primary feed categories listed above (i.e., facilities from the "other" category shown in Exhibit 2-14).

Source: Facility responses to the 1991 PCA survey.

Available data indicate that the cement industry consumes almost 1.6 metric tons of raw material per ton of clinker produced. The portion of raw material that does not become clinker is either lost on ignition or becomes CKD. Exhibit 2-15 shows typical ignition losses for each material type. Many of the feed materials, including limestone, can contain significant quantities of trace metals. Consequently, trace metal levels from feed materials in CKD can vary from plant to plant based on differences in feed mixture components. As stated above, the occurrence and impacts of trace metals are discussed further in Chapters 3, 5, and 7 of this report.

Fuels

The process of producing cement requires tremendous amounts of energy. The cost of this energy can constitute as much as 40 percent of total production costs for a cement facility.[82] The most energy-intensive part of the process is the maintenance of adequate temperatures inside the cement kiln.[83] As indicated in the discussion of the manufacturing process, material temperatures inside the kiln reach as high as 1,510°C (2,750°F). The heat source (combustion gas) must therefore be hotter than these materials, or hotter than the temperatures needed to form cement. In 1990, the average energy required for a kiln to produce one kg of clinker was 1,245 Kcals.[84]

The U.S. Bureau of Mines estimates that in 1990, the domestic cement industry consumed 71 trillion Kcals.[85] Industry responses to the 1991 PCA survey, however, suggest that this figure may be an underestimate. For example, 71 facilities that provided complete fuel information in the survey consumed an estimated 52 trillion Kcals. Also, the energy required to manufacture the nearly 70 million metric tons of clinker produced in 1990 at the average of 1,245 Kcals/kg (as estimated from the PCA surveys) would be over 81 trillion Kcals.

Clearly, the elevated combustion temperatures involved in cement production require fuels with a high heat content. Furthermore, the large volume of fuel consumed by the industry necessitates fuels that are available in large quantities at reasonable cost. Historically, these circumstances have dictated an almost exclusive reliance on fossil fuels of one type or another. Exhibits 2-17, 2-18, and 2-19 characterize fuel consumption by the cement industry in 1985 and 1990. These exhibits show that coal and, to a lesser extent, other fossil fuels have been and continue to be the primary fuels burned in most cement kilns. However, there has been a trend toward exploiting other, lower cost fuel alternatives, particularly waste fuels. In particular, a number of cement kilns across the country now fire non-hazardous solid wastes and/or hazardous waste liquids and solids as fuel. The following sections discuss the use of fossil fuels, solid waste fuels, and hazardous waste fuels in more detail.

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[82] Johnson, W., 1992, *op. cit.*

[83] Smith, J.D., 1990. Cement Kilns 1990, *EI Digest*, Environmental Information, Ltd. June 1990.

[84] Fuel consumption statistics for this report were derived from facility responses to the 1991 PCA survey. For more detailed information on the derivation of these statistics, refer to the Technical Background Document. These units were converted to Kcals from Btus as reported.

[85] Johnson, W., 1992, *op. cit.*

Exhibit 2-17

Cement Kiln Fuel Consumption in 1990 and 1985

Fuel Input	1990 Consumption[a]			1985 Consumption[b]		
	Total Consumption[c]	Energy Equivalent (million Kcals)	Percent of Total	Total Consumption	Energy Equivalent (million Kcals)	Percent of Total
Coal	5,548,250 metric tons	36,969,297	71.4%	5,838,240 metric tons	38,901,568	86.9%
Coke	866,732 metric tons	6,820,688	13.2%	518,274 metric tons	4,088,875	9.1%
Hazardous waste	NA	3,535,117	6.8%	NA	563,693	1.3%
Natural Gas	384 km^3	3,455,517	6.7%	121 km^3	1,087,839	2.4%
Oil	43,551 kiloliters	424,025	0.8%	12,452 kiloliters	124,253	0.3%
Solid waste	NA	491,003	0.9%	NA	2,666	0.0%
Other	NA	54,959	0.1%	NA	35,626	0.1%
Total	**—**	**51,750,606**	**100.0%**	**—**	**44,804,520**	**100.0%**

[a] Reflects 1990 fuel consumption for the 71 facilities for which data were available.

[b] Reflects 1985 fuel consumption for the 65 facilities for which data were available.

[c] The units in this table have been converted to metric from standard as reported.

NA: Data not available.

Source: Facility responses to the 1991 PCA survey.

Exhibit 2-18

Cement Kiln Fuel Mixtures in 1990

Primary Fuel(s)[a]	Number of Plants[b]	Supplemental Fuel[c] (Number of Plants Utilizing)						
		Coal	Natural Gas	Oil	Coke[d]	Solid Waste	Hazardous Waste	Other[e]
Coal	39	--	19	17	4	8	2	3
Coal, Coke	11	--	5	1	--	3	1	0
Coal, Coke, Hazardous Waste	6	--	3	2	--	2	--	2
Coal, Hazardous Waste	6	--	2	3	1	1	--	0
Coal, Natural Gas	5	--	--	1	2	1	1	0
Natural Gas, Coke	3	2	--	0	--	0	0	0
Natural Gas	2	0	--	1	0	1	0	0
Coal, Natural Gas, Coke	2	--	--	0	--	1	0	0
Coke, Hazardous Waste	2	0	2	0	0	0	--	0
Coal, Solid Waste	1	--	1	0	0	--	0	0
Coal, Oil	1	--	0	--	0	0	0	0
Solid Waste	1	0	1	0	0	--	0	0
Natural Gas, Oil, Coke	1	0	--	--	--	0	0	0
Natural Gas, Solid Waste	1	0	--	0	0	--	0	0
Total	**81**	**2**	**33**	**25**	**7**	**17**	**4**	**5**

[a] For purposes of this analysis, primary fuels are defined as those inputs that make up ten percent or more of the total heat value input.

[b] This exhibit presents information only for the 81 facilities for which 1990 fuel input information was available.

[c] For purposes of this analysis, supplemental fuels are those inputs that make up less than ten percent of the total heat value fed.

[d] Includes petroleum coke.

[e] Other fuels utilized in 1990 included: coke dust, carbon black, re-refined oil, carbon dust, and propane.

Source: Facility responses to the 1991 PCA survey.

Exhibit 2-19

Cement Kiln Fuel Mixtures in 1985

Primary Fuel(s)[a]	Number of Plants[b]	Supplemental Fuel[c] (Number of Plants Utilizing)						
		Coal	Natural Gas	Oil	Coke[d]	Solid Waste	Hazardous Waste	Other[e]
Coal	49	--	21	17	6	1	3	4
Coal, Coke	13	--	7	3	--	2	1	0
Coal, Natural Gas	4	--	--	2	1	0	0	0
Coal, Natural Gas, Coke	3	--	--	0	--	0	0	0
Natural Gas, Coke	1	0	--	1	--	0	0	0
Natural Gas	1	0	--	0	0	0	0	0
Coal, Hazardous Waste	1	--	0	0	0	0	--	0
Coal, Coke, Hazardous Waste	1	--	1	0	--	0	--	0
Natural Gas, Oil, Coke	1	0	--	--	--	0	0	0
Natural Gas, Coke, Hazardous Waste	1	1	--	0	--	0	--	0
Total	**75**	**1**	**29**	**23**	**7**	**3**	**4**	**4**

[a] For purposes of this analysis, primary fuels are defined as those inputs that make up ten percent or more of the total heat value input.

[b] This exhibit presents information only for the 75 facilities for which 1985 fuel input information was available.

[c] For purposes of this analysis, supplemental fuels are those inputs that make up less than ten percent of the total heat value fed.

[d] Includes petroleum coke.

[e] Other fuels utilized in 1985 included: coke dust, sublime pitch, re-refined oil, carbon dust, and propane.

Source: Facility responses to the 1991 PCA survey.

Fossil Fuels

Although the industry is now utilizing increasing amounts of alternative fuels, most cement kilns continue to combust traditional fossil fuels to produce the enormous process heat required for cement production. Fossil fuels still accounted for more than 90 percent of the total energy consumed in cement kilns in 1990. In contrast to the trend in the 1970's and early 1980's, when rising oil prices resulted in coal displacing oil as kiln fuel, there has been a recent trend away from coal toward other types of fossil fuels (coke, natural gas, and oil) and toward waste fuels. Exhibits 2-17, 2-18, and 2-19 show that coal's share of cement kiln fuel consumption declined from 1985 to 1990, both in terms of total energy provided and in the percentage of facilities using it. Coal, however, still remained the most commonly used fuel.

Most cement plants firing coal as a primary fuel obtain the coal from a local source. Data from the 1991 Keystone Coal Industry Manual suggest that most kilns usually obtain coal from within the same state or from the closest state with a sufficient coal supply. Coal is primarily organic matter consisting of carbon, hydrogen, oxygen, nitrogen, and sulfur. The composition of coal varies from place to place throughout the U.S. Coal is ranked according to composition into classes ranging from anthracitic to bituminous to subbituminous to lignitic. Exhibit 2-20 shows average coal composition by rank, and Exhibit 2-21 displays the geographic distribution of each rank.

Coal can contain significant quantities of sulfur, trace metals, and halogens, and their concentrations are dependent on the area in which the coal was mined. Consequently, contaminant levels attributable to coal in CKD can vary from plant to plant based on regional differences in coal composition. The occurrence of trace metals is discussed further in Chapter 3 of this report. Sulfur (in the form of SO_3) will vaporize in the kiln to form sulfur dioxide (SO_2), and condense in the form of sulfates. Within the kiln, these sulfates combine with calcium and potassium, causing operational problems in the cool end of the kiln.[86] Halogens are of concern because chlorides can cause operational problems similar to those caused by sulfur. Chlorine concentrations in coal can range from 100 to 2,800 parts per million.[87]

The other fossil fuels utilized in cement kilns include coke, natural gas, and oil. Coke is the solid, cellular, infusible material remaining after the carbonization of coal, pitch petroleum residues, and certain other carbonaceous materials.[88] The coke used by cement kilns is typically petroleum coke. Natural gas is a naturally occurring mixture of hydrocarbon and nonhydrocarbon gases found in the porous geologic formations beneath the earth's surface. Processed natural gas is principally methane, with small amounts of ethane, propane, butane, pentane, carbon dioxide, and nitrogen.[89] Because of its high heat transfer rate, natural gas is used to perform initial firing of kilns at many cement plants. When the kiln reaches operating temperature, the primary fuel is then brought on-line. Coke, natural gas, and oil are considered "cleaner" than coal because they contain less sulfur per Kcal provided.

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[86] Peray, 1986, *op. cit.*

[87] Environmental Toxicology International, 1992, *op. cit.*

[88] Perry's Chemical Engineers' Handbook, 1984, *op. cit.*

[89] Kirk-Othmer, 1979, *op. cit.*

Exhibit 2-20
Average Coal Composition by Rank

	Average	Anthracite	Bituminous	Subbituminous	Lignite
Kcal (per kg.)	6,210	7,100	6,820	5,230	2,780
Moisture	10.0	1.4	4.8	18.4	41.5
Volatile matter	29.9	6.5	32.3	33.8	23.0
Fixed carbon	48.8	79.5	51.2	39.0	20.9
Ash	11.3	12.6	11.7	8.8	14.6
Hydrogen	5.1	2.4	5.0	5.9	6.8
Carbon	64.1	80.1	69.1	54.3	29.9
Nitrogen	1.1	0.8	1.3	1.0	0.5
Oxygen	16.4	3.2	10.3	29.3	46.5
Sulfur	2.0	0.8	2.7	0.7	1.7
Sulfate sulfur	0.12	0.02	0.16	0.04	0.24
Pyritic sulfur	1.19	0.35	1.70	0.35	0.68
Organic sulfur	0.70	0.48	0.88	0.32	0.75

(All values except Kcals in weight percent)

[a] These units have been converted to Kcal/kg from Btus/lb as reported.

Sources: Swanson, V.E., et al., 1976. *Collection, Chemical Analysis, and Evaluation of Coal Samples in 1975*, U.S. Geological Survey, Open File Report 76-468.

Exhibit 2-21
Coal Producing Regions of the United States and Coal Types Produced

Region	Coal Ranks Produced
Eastern Province (Alabama, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia)	Primarily anthracite, with large deposits of bituminous
Interior Province (Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Missouri, Nebraska, Oklahoma)	Medium- to high-volatile bituminous, with smaller volumes of low-volatile bituminous and anthracite
Gulf Province (Alabama, Arkansas, Mississippi, Texas)	Lignite
Northern Great Plains Province (Montana, North Dakota, Wyoming)	Lignite, subbituminous
Rocky Mountain Province (Arizona, Colorado, New Mexico, Utah, Wyoming)	Bituminous, subbituminous
Pacific Coast Province (Washington)	Bituminous, subbituminous, lignite

Source: Magee, E.M., et al., 1973. *Potential Pollutants in Fossil Fuels*, prepared for U.S. Environmental Protection Agency, Esso Research and Engineering Co., Linden, New Jersey. June 1973.

Exhibit 2-22 compares relative costs per unit of energy of each of the fossil fuels. Coal (or at least bituminous, subbituminous, and lignite coal) is inexpensive compared to the other fuel types, which certainly contributes to its dominance as the primary energy source for cement kilns. However, natural gas prices have fallen much more rapidly than coal prices over the last five years. These reduced prices, combined with the lower sulfur content of natural gas, may help explain its increasing share of the kiln fuel market. Moreover, domestic supplies of both coal and natural gas are abundant, providing a more secure long-term fuel source, as compared to oil.

Exhibit 2-22

Nominal Fossil Fuel Prices in 1985 and 1990

Fuel	1990 Price (cents per million Kcals)	1985 Price (cents per million Kcals)	Percent Change
Coal (Anthracite)	692.7	810.6	- 14.5
Coal (Bituminous, Subbituminous, and Lignite)	395.0	455.7	- 13.3
Natural Gas	613.7	896.0	- 31.5
Oil	1,370.8	1,648.7	- 16.9
Coke	Not Available	Not Available	--

Source: Energy Information Administration, 1992. *Annual Energy Review 1991*. June 1992.

Non-hazardous Waste Fuels

In an effort aimed largely at reducing production costs, the cement industry has been actively investigating alternative fuel sources. As a result, there has been a significant increase in the use of wastes, both hazardous and non-hazardous, as fuels by cement kilns. Three facilities reported using small amounts of non-hazardous solid waste[90] as supplemental fuels in 1985. By comparison, 20 facilities reported using solid waste as either primary or supplemental fuel in 1990. One of these facilities even obtained the majority (over 70 percent) of the energy it consumed from solid waste (waste oil). The primary types of non-hazardous solid waste used as fuel in 1990 were used tires and waste oil. One facility reported using waste wood chips as fuel. Exhibit 2-23 further details the consumption of solid waste fuel by type. Reportedly, the industry is also evaluating other types of non-hazardous solid waste, including almond shells and municipal solid waste, for use as kiln fuel.[91] Although available waste fuel price data are extremely limited, it is EPA's understanding that the burning of such alternative fuels can be done at zero net cost or even at a small profit to cement plant operators.

[90] The term, "solid waste", is used throughout this analysis in its regulatory sense. The term does not have a direct relationship to the physical form of the material and includes sludges and liquid wastes (such as waste oil) as well as solids.

[91] Portland Cement Association, 1992a, *op. cit*.

Exhibit 2-23

Breakdown of Solid Waste Fuel Consumption[c]

Solid Waste	1990 Consumption[a]			1985 Consumption[b]		
	Total Consumption	Energy Equivalent (million Kcals)	Percent of Total	Total Consumption	Energy Equivalent (million Kcals)	Percent of Total
Tires	69,228 metric tons	278,391	56.7%	0	0	0.0%
Waste Oil	19,148 kiloliters	207,841	42.3%	314 kiloliters	2,666	100.0%
Wood Chips	943 metric tons	4,792	1.0%	0	0	0.0%
Total	**--**	**491,024**	**100.0%**	**--**	**2,666**	**100.0%**

[a] Reflects 1990 fuel consumption for the 71 facilities for which data were available.

[b] Reflects 1985 fuel consumption for the 65 facilities for which data were available.

[c] These units have been converted to metric units from the standard units reported.

Source: Facility responses to the 1991 PCA survey.

Hazardous Waste Fuels

In addition to increasing consumption of solid waste fuels, cement kiln operators have substantially increased the consumption of hazardous wastes as fuel, which has come to account for a significant portion of fuel consumption by cement kilns. Available data indicate that hazardous waste fuels now supply as much of the total energy consumed as natural gas (see Exhibit 2-17). The remainder of this section discusses the hazardous waste fuels industry in general, the extent of hazardous waste consumption by kilns, the types of hazardous waste burned, the technologies used to feed the waste to kilns, and environmental regulations applicable to this practice. The section concludes by highlighting some of the subjective arguments made by supporters and opponents of burning hazardous wastes in cement kilns.

Overview of the Hazardous Waste Fuels Industry

As part of EPA's RCRA Subtitle C Land Disposal Restrictions (LDR) Program (see 40 CFR Part 268), EPA has established treatment standards that must be met before a hazardous waste may be land-disposed. These standards are based on the performance of the Best Demonstrated Available Technology (BDAT). For most non-aqueous wastes contaminated with organic constituents (e.g., solvents, petroleum refining wastes), EPA has determined that incineration is the BDAT. Use as fuel in boilers or industrial furnaces (BIFs) (e.g., cement kilns) is an acceptable means of complying with LDRs for many of these wastes. Because of the significant demand for treatment of hazardous wastes, the limited availability of and high price of using commercial hazardous waste incinerators, and the sizable fuel requirements of cement kilns, cement kilns can successfully compete with commercial incinerators in the waste treatment market, and have become a major component of the commercial hazardous waste management industry.

Because the business of managing hazardous wastes is quite different from the business of manufacturing cement, and because cement plants are often located far from waste generators, many cement companies rely on intermediate fuel processors to supply them with waste fuels. These fuel processors may be located at the cement plant site, but more often they are not. The fuel processor typically accepts or collects wastes from many individual waste generators and stores and blends wastes to meet cement kiln specifications. In some cases, these fuel processors also manage or participate in hazardous waste fuel management activities (e.g., sampling and recordkeeping) at the cement facility. Waste fuels may be stored in tanks or in container storage areas prior to being fed to the kiln or, in some cases, may be fed directly from tanker trucks.

Extent of Hazardous Waste Consumption by Cement Kilns and Types of Waste Burned

Environmental Information Digest lists 23 cement plants that were routinely burning hazardous waste in 1990.[92] Eighteen of the 81 facilities that provided fuels information in response to the 1991 PCA survey reported burning hazardous waste as either primary or supplemental fuel. As noted above and shown in Exhibits 2-17, 2-18, and 2-19, the practice of burning hazardous waste in cement kilns has increased significantly during the last five years, both in terms of the number of facilities utilizing hazardous waste and in terms of percent of total energy consumed.

Exhibit 2-24 provides information on the physical form of hazardous wastes burned in cement kilns. Although liquid wastes comprise most of the hazardous wastes consumed, cement plant operators also have expanded their consumption of hazardous wastes in solid form in recent years. In

Exhibit 2-24

Breakdown of Hazardous Waste Fuel Consumption

Hazardous Waste Physical Form	1990 Consumption[a]		1985 Consumption[b]	
	Energy Equivalent (million Kcals)	Percent of Total	Energy Equivalent (million Kcals)	Percent of Total
Solid	123,822	3.5%	0	0.0%
Liquid	3,411,450	96.5%	563,718	100.0%
Sludge	0	0.0%	0	0.0%
Total	**3,535,272**	**100.0%**	**563,718**	**100.0%**

[a] Reflects 1990 fuel consumption for the 71 facilities for which data were available.

[b] Reflects 1985 fuel consumption for the 65 facilities for which data were available.

[c] These units have been converted to Kcals from Btus as reported.

Source: Facility responses to the 1991 PCA survey.

[92] Smith, J.D., 1991. Cement Kilns 1991, *EI Digest*, Environmental Information, Ltd. August 1991.

addition, though several facility operators have reported that they have the capacity to burn hazardous waste sludges,[93] none (in the 1991 PCA survey) reported burning waste in this form.

Hazardous Waste Fuel Technologies

Several different technologies are employed to feed hazardous waste fuels into cement kilns. These different methods are important in that they dictate the types of wastes that a kiln can burn (i.e., liquid, sludge, or solid) and the location of the waste entry point relative to the flame in the kiln. In general, there are four important types of feed systems:

- Liquid feed systems, whereby liquid waste fuels are fed either through primary (fossil fuel) fuel ports or through similar ports in the hot end of the kiln;
- Sludge feed systems, which are similar to liquid feed systems except that they have higher solids, particle size, and viscosity tolerances;
- Dry solids systems, in which dry, finely divided waste particles (like coal dust) are blown into the flame area of the kiln; and
- Container feed systems, in which small buckets or bags are fed to the mid-section or calcining zone of the kiln. In wet process kilns, containers are fed at the mid-point of the kiln, while in preheater/precalciner kilns, containers are fed at the cool end, between the preheater and the rotating kiln body.

Relevant Environmental Regulations

Until August 1991, the burning of hazardous waste as fuel in cement kilns was exempt from RCRA permitting requirements under the premise that this practice constituted recycling. As a guideline for identifying recycling, EPA established a minimum waste heating value limit of 2,780 Kcal/kg. Hazardous waste fuel burners meeting this limit were required to notify EPA of their activities, obtain an EPA identification number, and maintain certain records (40 CFR 266.36).

On February 21, 1991 (56 FR 7134), EPA promulgated new rules to control the burning of hazardous waste in boilers and industrial furnaces. The so-called Boiler and Industrial Furnace (BIF) Rule controls the emissions of toxic organic compounds, toxic metals, hydrogen chloride (HCl), chlorine gas (Cl_2), and particulate matter from boilers and industrial furnaces that burn hazardous wastes. In particular, the BIF Rule establishes, at 40 CFR Part 266, Subpart H, the following regulatory compliance criteria:

- Demonstrate 99.9999 percent destruction or removal of dioxin-listed wastes and 99.99 percent destruction or removal of all other hazardous organic constituents;
- Adhere to limits on carbon monoxide and/or hydrocarbon flue gas concentrations;
- Meet risk-based (i.e., health-based) emission limits for four carcinogenic metals (arsenic, beryllium, cadmium, and chromium), six noncarcinogenic metals (antimony, barium, lead, mercury, silver, and thallium), HCl, and Cl_2. Under EPA's tiered approach to metal standards, higher emissions rates and feed rates are permitted as more detailed, site-specific emissions testing and dispersion modeling are conducted;

[93] U.S. Environmental Protection Agency, 1990. *Commercial Combustion Capacity for Hazardous Waste Sludges and Solids*, Office of Solid Waste, Washington, D.C. August 1990.

- Limit particulate matter emissions to 0.08 gr/dscf, corrected to 7 percent oxygen (the same standard required of hazardous waste incinerators); and

- Comply with general facility standards specified under 40 CFR 264 for hazardous waste treatment, storage, and disposal facilities.

Affected facilities were given until August 21, 1991 to notify EPA of their waste burning practices and their plans for certifying precompliance with the rule. With few exceptions, BIF operators were required to certify compliance with interim status standards by August 21, 1992. The rule did not place a deadline on final permit decisions. [Note to reader: EPA recently granted a stay to the two-part test.]

2.3 SUMMARY AND RELEVANCE TO SUBSEQUENT CHAPTERS

This chapter presented an overview of the cement industry and the basic cement manufacturing process. The discussion of the industry's structure and description of kiln technology presented herein will assist the reader in understanding the issues raised in subsequent chapters of this report. Specifically, the overview of the cement industry serves as an introduction that will result in a clearer understanding of the economic impacts of potential CKD regulation (see Chapter 9). The discussion of production technologies provides the reader with the industry-specific knowledge needed to understand the current CKD collection, recycling, and management practices discussed in Chapters 3 and 4 and management alternatives presented in Chapter 8. Finally, the last section of this chapter on process inputs will help the reader understand the connection between raw material and fuel inputs to cement making and the chemical characteristics of CKD, a topic that is discussed more fully in Chapter 3.

CHAPTER TWO

CEMENT INDUSTRY OVERVIEW

LIST OF EXHIBITS